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Scaled Eagle Nebula Experiments on NIF

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Research Performance Progress Report

Program HEDLP LAB 11-583 — Office of Fusion Energy Sciences
High Energy Density Laboratory Plasmas

Project Title: Scaled Eagle Nebula Experiments on NIF

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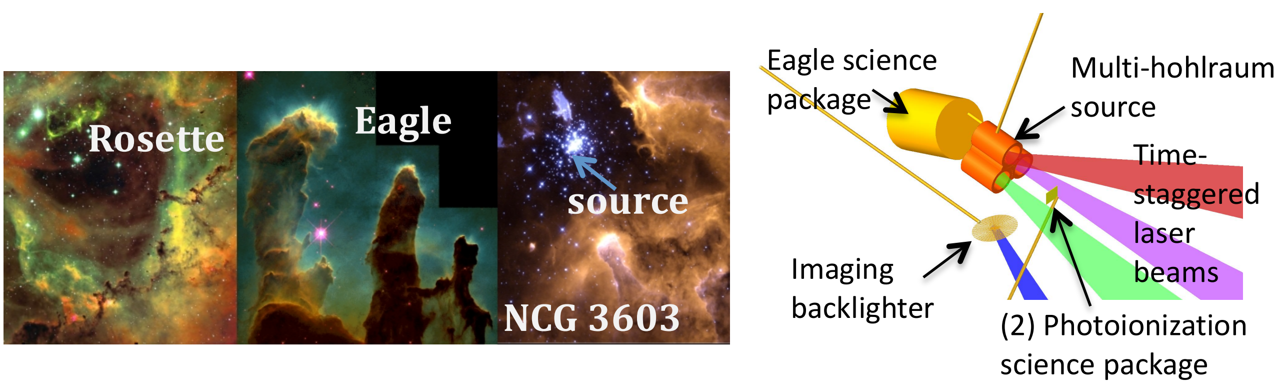

Figure 1. Left: Rosette Nebula; Pillars of the Eagle Nebula; NGC 3603. Pillars in molecular clouds point towards nearby clusters of bright young stars. Right: NIF experiment will quantify dynamics driving the evolution of star-forming pillar structures. The Eagle target is 'stood off' from x-ray generating radiation cavities (hohlraums) so that the target is directionally irradiated by a cluster of stellar-like sources. The hohlraums are driven for 10 ns each in series, giving a total x-ray output lasting 30 ns.

1. Accomplishments

What are the major goals of the project?

"Scaled Eagle Nebula Experiments on NIF" was recommended for the National Ignition Facility (NIF) laser time through the Science Use of NIF Program. This HEDLP effort is to design and execute the Eagle shots. The project objectives are to

1. Develop a collimated long duration NIF drive.
2. Use the new drive to generate, for the first time, long-duration highly directional irradiation, ablation, and compression of scaled targets.
3. Investigate novel dynamics of photoionization fronts in star forming structures of molecular clouds irradiated by luminous O-type stars, such as the iconic Pillars of the Eagle Nebula (Figure 1.)
4. Quantitatively compare the results to astronomical observations.

What was accomplished under these goals? What was done and learned?

1. Validated NIF concepts with 7 more shots at the Omega EP laser (Figure 2, Figure 3, Figure 5)

Eagle's 2nd day of 7 Laboratory Basic Science (LBS) shots was completed at the Omega EP laser at the University of Rochester Laboratory for Laser Energetics. X-ray backlighting of a prototype Eagle science package stood off from a refined, lower-mass (lower-debris) multi-hohlraum source was successfully demonstrated. As on the 1st day of LBS shots, spectral data was also obtained from a second science package on the same shots — the accretion disk photoionization package.

2. Astrophysical simulations (Figure 4)

Marc Pound and Mark Wolfire were trained in the use of the astrophysical code V2 that Dr. Kane wrote and used to simulate radiative hydrodynamics of the Eagle Nebula, and were given Collaborator status access to computing resources at LLNL.

3. Preliminary design of NIF experiment (Figure 5)

A preliminary design for a NIF experiment that generates a cometary pillar structure that can be observed in x-ray backlighting was produced.

4. Eagle NIF Shots awarded and scheduled for FY15-16

Following a presentation by to the NIF Science Technical Review Committee, where the LBS shots and the preliminary NIF design were shown, Eagle was recommended for 2 days of NIF shots (4 shots) in FY15-16, and these shots have been scheduled.

5. Third day of Laboratory Basic Science shots awarded

Eagle Experimentalist Dr. David Martinez was awarded Eagle's 3rd day of LBS Omega EP shots, to investigate 4-ω shadography of a low-density ablated plasma of the type that forms the cometary tail in the NIF experiment.

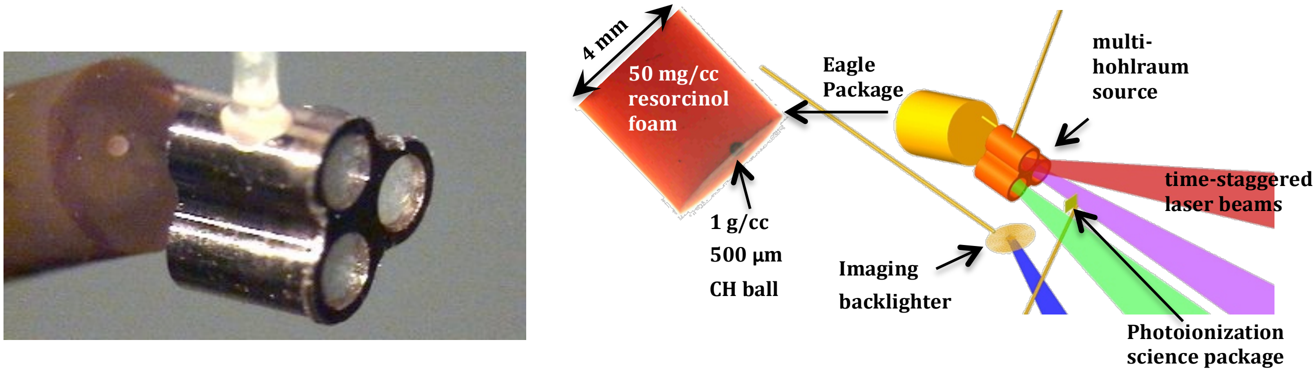

Figure 2. Left: a three-hohlraum source and an Eagle Science package. Right: VisRad drawing of the experiment, showing the source, science packages, and backlighter.

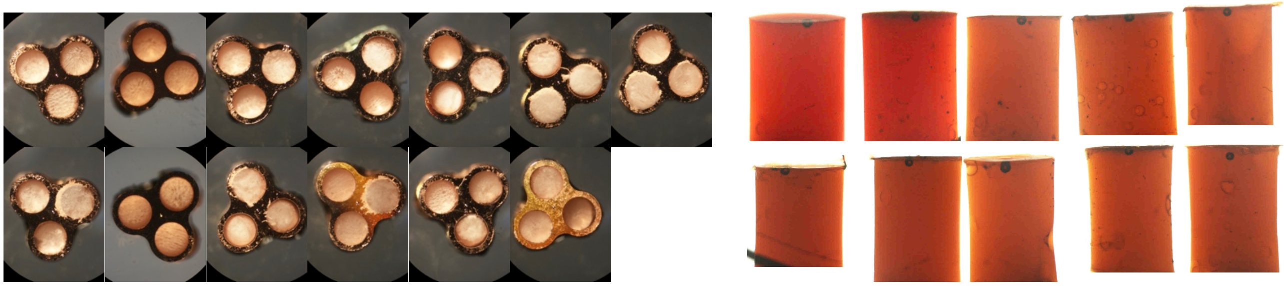

Figure 3. Left: the 13 multi-hohlraum sources built for the 2nd day of Omega EP LBS shots. Right: 10 of the Eagle science packages targets built for the 2nd day of LBS shots.

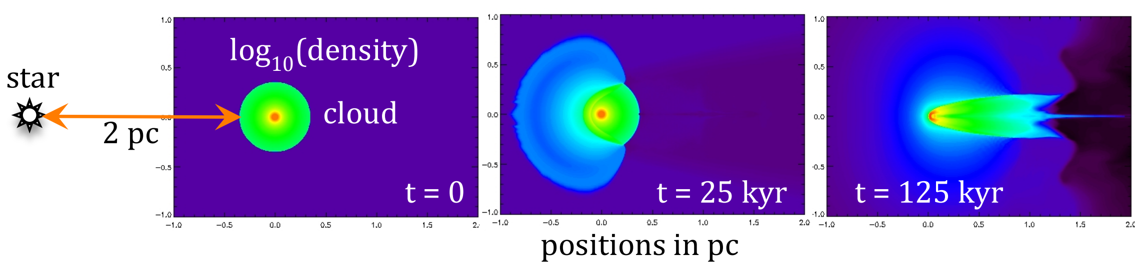

Figure 4 Astrophysical simulation of cometary model using code V2.

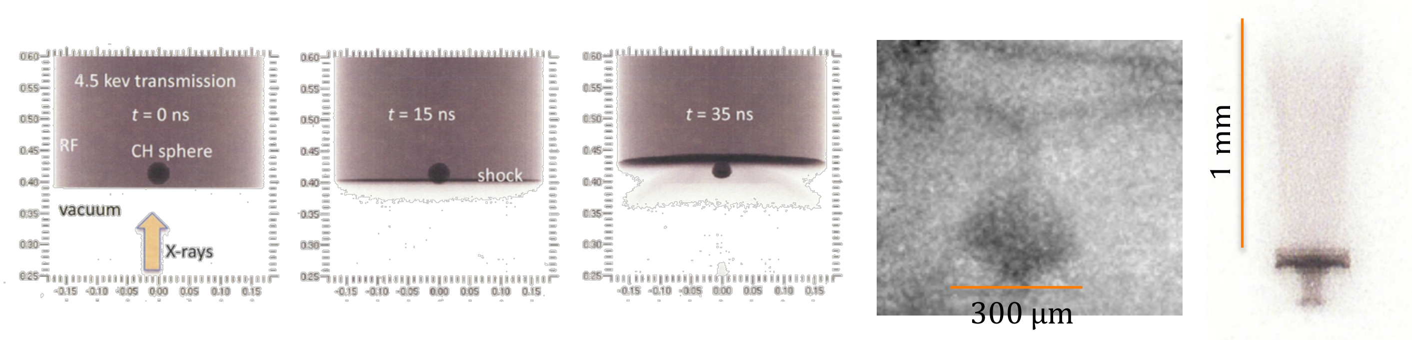

Figure 5 Left: HYDRA simulation of shock moving past embedded sphere in Eagle science package at Omega. 2nd from right: radiograph of shocked sphere. Right: simulated radiograph of much more evolved NIF cometary pillar predicted by HYDRA.

How have the results been disseminated to communities of interest?

Dr. Kane and Dr. Pound gave a joint seminar on the project at LLNL, following which Dr. Kane was invited to give a talk at the SPIE Photonics West conference in February 2015. Dr. Kane and Dr. Martinez are preparing a paper presenting the science results from the first two days of Omega EP LBS shots, and a second paper discussing technical aspects of the new multi-hohlraum source.

What do you plan to do during the next reporting period to accomplish the goals?

1. Select a final design for the NIF Eagle science package and validate proposed experiments with NIF review committees (Figure 6).
2. Perform one NIF shot to validate the NIF-scale version of the multi-hohlraum source, and perform one data shot to obtain first backlight images of a cometary pillar. Possibly obtain Fe K-shell spectral data from an accretion disk photoionization package on the same shots.
3. Carry out the 3rd day of Omega EP LBS shots, testing 4-ω shadography.
4. Publish results of first two days of LBS shots.
5. Process Eagle data from 1st NIF shots with Dr. Pounds 'synthetic pipeline' and examine implications for pillar structures in molecular clouds.

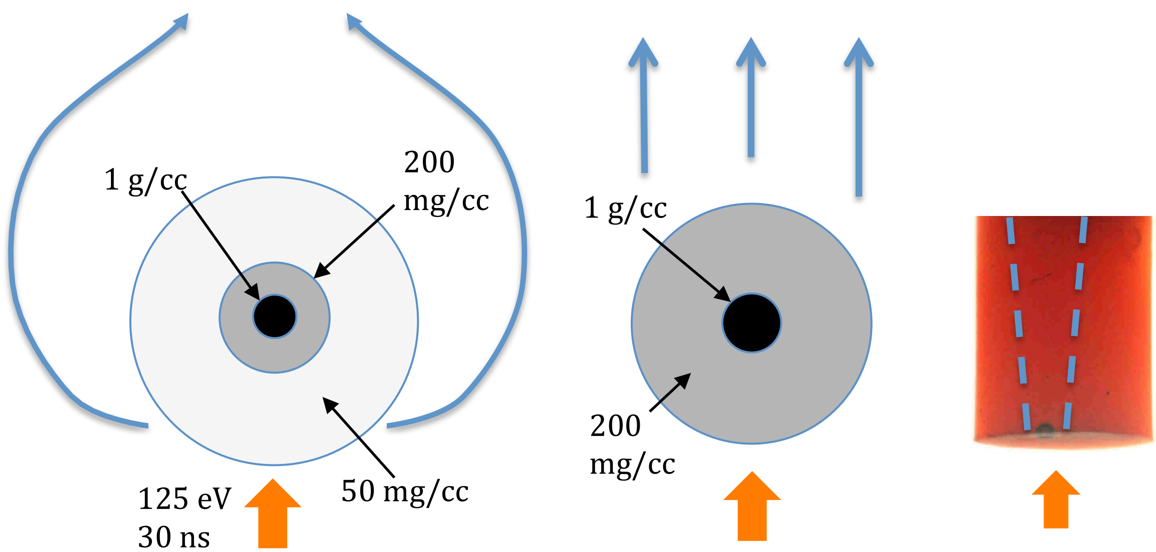

Figure 6. Three of the designs under consideration for the NIF Eagle science package. Left: idealized design with stepped densities mimicking the cloud in the astrophysical simulation shown in Figure 2; tail forms when ablated outer collects behind the dense core. Middle: two-step design with higher densities to generate cometary tail from material shock-released from back of cloud. Right: same as shot at Omega EP; clump embedded in dense cloud; pillar forms from material shadowed by dense clump.

2. Products

Dr. Martinez and Dr. Kane are preparing a paper presenting the science results from the first two days of Omega EP LBS shots, and a second paper discussing technical aspects of the new multi-hohlraum source.

Dr. Kane and Dr. Pound gave a joint seminar on the project at LLNL, following which Dr. Kane was invited to give a talk at the SPIE Photonics West conference in February 2015. Dr. Kane and Martinez gave a joint talk to Technical NIF Science Technical Review Committee. Dr. Kane presented the Eagle project at the NIF User Group meeting.

3. Participants and other collaborating organizations

Postdoc David Martinez, who was recently promoted to a staff position at LLNL.
Dr. Robert Heeter, Dr. Jim Emig, Dr. Russell Wallace, LLNL.
Dr. Roberto Mancini, University of Nevada.
Dr. Reny Paglio, Dr. Mike Farrell, General Atomics San Diego; Dr. Diana Schroen, General Atomics, Albuquerque.

Marc W. Pound and Mark Wolfire, University of Maryland (under DE-FOA-000583).

Dr. Alexis Casner and Dr. Bruno Villette, CEA/CESTA/DAM, France.

4. Impact

The project provides insight into (1) how pillar structures form in HII regions of astrophysical molecular clouds, (2) whether an ablatively confined cometary tail is a valid model for pillars, and (3) the implications for star formation. The results of the project can guide new ground based observations of molecular clouds.

The project investigates the more general area of deeply nonlinear hydrodynamic instabilities in the presence of sustained, highly directional illumination. The NIF experiments could also generate exotic instabilities so far seen only in theory and in astrophysical simulations — the 'Tilted' and 'Directed' radiation instabilities.

The project introduces a new platform concept to the high-power laser experimental community — a long duration drive (lasting 30 ns.) This drive already presents the opportunity to greatly improve our ability to study stably photoionized (as opposed to collisionally ionized) plasmas. The Eagle work may spur development of much longer NIF pulses, possibly 50-100 ns, permitting study of highly nonlinear radiative hydrodynamics.

This project studies a very appealing astrophysical object — the Pillars of Creation in the Eagle Nebula. It underlines the idea that the human intellect can use mathematical equations, computer codes, and millimeter-size objects that last nanoseconds in a laboratory to study parsec-scale objects thousands of light years distant that last for hundreds of thousand of years, and which evolve by the same physical laws as those on Earth. This in turn raises the appeal of the STEM disciplines and contributes to the economic competitiveness of the nation.

None of the award's budget is being spent in foreign countries. The French collaborators from CEA/CESTA/DAM supply and run their spectrometers at their expense.

5. Changes/Problems

Remaining funding

Following a lengthy (yet very profitable) diversion to Omega EP, less than 0.5 FTE of Eagle HEDLP funding remains, just when NIF shots have finally been scheduled. Realistically, an additional 1.0 FTE is needed to design the NIF-scale version of the experiment, steer the experimental plan through multiple NIF, execute the shots, and analyze and publish the results. Dr. Kane has neither programmatic support nor LDRP prospects for Eagle. Dr. Kane has requested partial funding from NASA ARA Laboratory Astrophysics, but the odds are approximately 10:1.

While waiting for NIF shots, Eagle has successfully mustered resources to make significant progress. Eagle has been awarded highly competitive LBS shots for three straight years. In addition, Eagle has benefited from significant value multipliers:

1. LBS provided the following for free: target fabrication at General Atomics (GA) San Diego and GA Albuquerque, Omega EP laser time, and LLE staff effort. Dr. Paglio and Dr Schroen at GA did ingenious and heroic work developing the multi-hohlraum source, its foam fill, the VISAR package (fielded on the 1st day of LBS shots to validate the source), and the Eagle science package.
2. Drs. Alexis Casner and Bruno Villette of CEA deployed the μ-DMX and mini-DMX spectrometers on the LBS shots at no charge to Eagle. Those diagnostics were crucial to demonstrating the performance of the multi-hohlraum source and the photoionization science package.
3. While David Martinez was partly funded by this HEDLP grant to work on Eagle, he was also willing to contribute from the 25% elective institutional part of his postdoctoral salary that was funded by the LLNL Director's Office. Without this, the LBS shots would not have been possible.

It is reasonable to expect that new funding would also enjoy large value multipliers.